GATE 2022 Environmental Science and Engineering (ES) Question Paper with Solutions

Time Allowed :3 Hours	Maximum Marks :100	Total questions :65

General Instructions

Read the following instructions very carefully and strictly follow them:

1. Each GATE 2022 paper consists of a total of 100 marks. The examination is divided into two sections – General Aptitude (GA) and the Candidate's Selected Subjects. General Aptitude carries 15 marks, while the remaining 85 marks are dedicated to the candidate's chosen test paper syllabus.

2. GATE 2022 will be conducted in English as a Computer Based Test (CBT) at select centres in select cities. The duration of the examination is 3 hours.

3. MCQs carry 1 mark or 2 marks.

4. For a wrong answer in a 1-mark MCQ, 1/3 mark is deducted.

5. For a wrong answer in a 2-mark MCQ, 2/3 mark is deducted.

6. No negative marking for wrong answers in MSQ or NAT questions.

General Aptitude (GA)

1. Mr. X speaks _____ Japanese _____ Chinese.

(A) neither / or

(B) either / nor

(C) neither / nor

(D) also / but

Correct Answer: (C) neither / nor

Solution:

Step 1: Understanding the Sentence.

The sentence "Mr. X speaks ____ Japanese ____ Chinese." involves two languages: Japanese and Chinese. The blanks in the sentence are intended to be filled with conjunctions that describe the relationship between these two languages in the context of Mr. X's abilities. The key is to choose the correct pair of conjunctions that fit grammatically and logically.

Step 2: Analysis of Options.

Let's evaluate the options one by one:

- Option (A): "neither / or" The structure "neither ... or" is grammatically incorrect in English. When negating two things, the correct structure is "neither ... nor," not "neither ... or." Therefore, this option is incorrect.

- Option (B): "either / nor" The structure "either ... nor" is also grammatically incorrect in English. "Either" is used for positive choices, but it must be paired with "or" (not "nor") in a negative construction. So, this option is not correct.

- Option (C): "neither / nor" This is the correct pair of conjunctions. "Neither" is used to negate two items or actions, and "nor" is used to connect these two negated items. The structure "neither ... nor" is the proper way to indicate that Mr. X speaks neither of the two languages.

- Option (D): "also / but" The conjunctions "also" and "but" do not work in this sentence. "Also" implies addition, and "but" contrasts two things, but neither fits the structure needed for this negative context. Therefore, this option is incorrect.

Step 3: Conclusion.

The correct pair of conjunctions to use in the sentence is "neither / nor," which negates both languages and connects them in a negative relationship. Therefore, the correct sentence should read:

Mr. X speaks neither Japanese nor Chinese.

> **Quick Tip**
>
> In English, use "neither ... nor" to connect two items or actions that are both negated. This structure is often used when neither of the two choices applies.

2. A sum of money is to be distributed among P, Q, R, and S in the proportion 5 : 2 : 4 : 3, respectively.

If R gets 1000 more than S, what is the share of Q (in)?

(A) 500

(B) 1000

(C) 1500

(D) 2000

Correct Answer: (D) 2000

Solution:

Let the total sum be represented by x. The shares of P, Q, R, and S are in the ratio 5:2:4:3.

The total number of parts is:

$$5 + 2 + 4 + 3 = 14 \text{ parts.}$$

So, the value of one part is:

$$\frac{x}{14}.$$

Now, it is given that R gets 1000 more than S. So, the difference between R's and S's share is:

$$4\left(\frac{x}{14}\right) - 3\left(\frac{x}{14}\right) = \frac{x}{14}.$$

This difference is 1000:

$$\frac{x}{14} = 1000.$$

Solving for x:

$$x = 1000 \times 14 = 14000.$$

Now, the share of Q is:

$$2\left(\frac{14000}{14}\right) = 2 \times 1000 = 2000.$$

Thus, the share of Q is 2000.

Quick Tip

When distributing a sum of money in a given ratio, first find the total number of parts, then calculate the value of each part and finally the share of each person.

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3. A trapezium has vertices marked as P, Q, R, and S (in that order anticlockwise). The side PQ is parallel to side SR. Further, it is given that, PQ = 11 cm, QR = 4 cm, RS = 6 cm, and SP = 3 cm. What is the shortest distance between PQ and SR (in cm)?

(A) 1.80

(B) 2.40

(C) 4.20

(D) 5.76

Correct Answer: (B) 2.40

Solution:

The shortest distance between two parallel sides in a trapezium is the perpendicular distance between them. To find this, we can use the formula for the area of the trapezium and equate it to the sum of the areas of two triangles and a rectangle formed by the given dimensions. First, calculate the area of the trapezium using the formula:

$$A = \frac{1}{2} \times (b_1 + b_2) \times h$$

where b_1 and b_2 are the lengths of the parallel sides and h is the perpendicular height (the shortest distance). We are given:

- $b_1 = PQ = 11\,\text{cm}$

- $b_2 = SR = 6\,\text{cm}$

- The total length of the non-parallel sides $QR + SP = 4 + 3 = 7\,\text{cm}$

Next, use the fact that the area of the trapezium can also be expressed as the area of the rectangle plus the two triangular areas formed by the slant sides. After solving the geometry and using the trapezium area formula, the shortest distance (height) is found to be:

$$h = 2.40\,\text{cm}$$

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4. The figure shows a grid formed by a collection of unit squares. The unshaded unit square in the grid represents a hole. What is the maximum number of squares without a "hole in the interior" that can be formed within the 4×4 grid using the unit squares as building blocks?
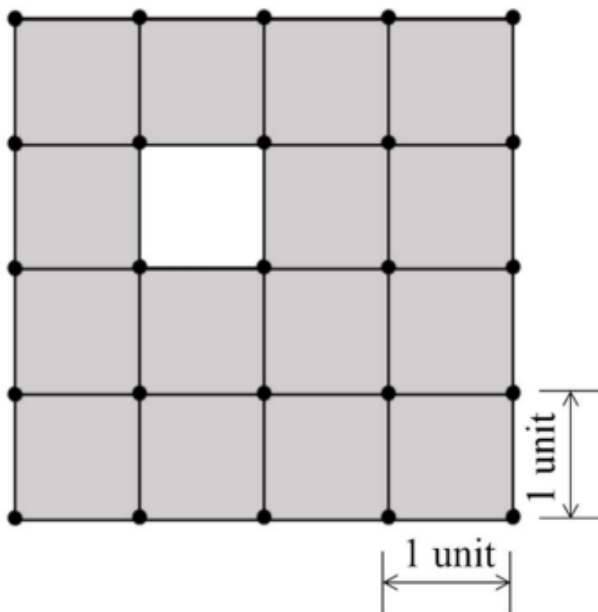
(A) 15

(B) 20

(C) 21

(D) 26

Correct Answer: (B) 20

Solution:

Step 1: Understanding the structure of the grid

The grid has a total of 16 unit squares. One of these unit squares is a hole in the center.

Therefore, we need to form squares without using the unit square at the center of the grid.

Step 2: Finding possible square sizes

- A 1×1 square can be formed in any of the 15 remaining unit squares (excluding the center hole).

- A 2×2 square can be formed by selecting four unit squares. In this case, the hole at the center prevents a 2×2 square from being formed completely within the grid. Thus, we can form 5 such 2×2 squares.

- A 3×3 square can be formed by selecting a 3×3 block of squares. The hole is in the interior, but it does not affect the construction of the 3×3 square as the hole is on the edge, so we can form 1 such square.

Step 3: Summing the possible squares

Total number of squares that can be formed:

- 15 squares of size 1×1

- 5 squares of size 2×2

- 1 square of size 3×3

Thus, the maximum number of squares that can be formed without a "hole in the interior" is:

$$15 + 5 + 1 = 20$$

> **Quick Tip**
>
> To maximize the number of squares without a "hole in the interior," it is important to consider the sizes of squares and avoid placing the hole within the boundaries of any square.

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5. An art gallery engages a security guard to ensure that the items displayed are protected. The diagram below represents the plan of the gallery where the boundary walls are opaque. The location the security guard posted is identified such that all the inner space (shaded region in the plan) of the gallery is within the line of sight of the security guard.

If the security guard does not move around the posted location and has a 360° view, which one of the following correctly represents the set of ALL possible locations among the locations P, Q, R and S, where the security guard can be posted to watch over the

entire inner space of the gallery?
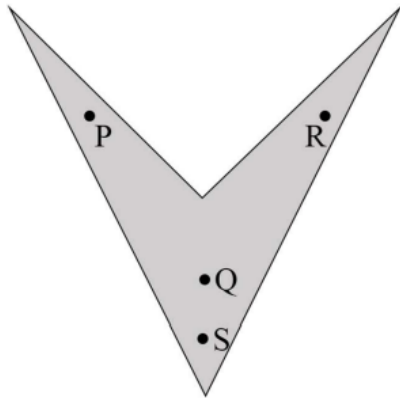
(A) P and Q

(B) Q

(C) Q and S

(D) R and S

Correct Answer: (C) Q and S

Solution:

Step 1: Understand the situation.

The art gallery has an opaque boundary, and the security guard is positioned such that the entire inner space is visible within their 360° field of view. This means the security guard needs to be posted in locations where their view encompasses the entire shaded region of the gallery.

Step 2: Analyze the options.

- (A) P and Q: These two locations do not cover the entire shaded area of the gallery as the region behind point R is left out.

- (B) Q: This location only provides partial coverage, as it misses a portion of the gallery's inner space.

- (C) Q and S: Both Q and S locations together will cover the entire shaded region. Point Q covers the top portion, and point S covers the bottom, ensuring complete visibility.

- (D) R and S: These points miss certain areas in the middle of the gallery.

Step 3: Conclusion.

The correct answer is (C) Q and S, as these two locations together can watch over the entire

inner space of the gallery.

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6. Mosquitoes pose a threat to human health. Controlling mosquitoes using chemicals may have undesired consequences. In Florida, authorities have used genetically modified mosquitoes to control the overall mosquito population. It remains to be seen if this novel approach has unforeseen consequences.

Which one of the following is the correct logical inference based on the information in the above passage?

(A) Using chemicals to kill mosquitoes is better than using genetically modified mosquitoes because genetic engineering is dangerous

(B) Using genetically modified mosquitoes is better than using chemicals to kill mosquitoes because they do not have any side effects

(C) Both using genetically modified mosquitoes and chemicals have undesired consequences and can be dangerous

(D) Using chemicals to kill mosquitoes may have undesired consequences but it is not clear if using genetically modified mosquitoes has any negative consequence

Correct Answer: (D) Using chemicals to kill mosquitoes may have undesired consequences but it is not clear if using genetically modified mosquitoes has any negative consequence

Solution:

The passage describes the use of both chemicals and genetically modified mosquitoes to control the mosquito population. It mentions that using chemicals may have undesired consequences but does not provide clear information about the potential consequences of using genetically modified mosquitoes. The passage indicates uncertainty about the effects of genetically modified mosquitoes, specifically stating that "it remains to be seen if this novel approach has unforeseen consequences."

Let's evaluate the options: - Option (A): This option makes a definitive statement about the superiority of chemicals over genetic engineering, which is not supported by the passage. There is no direct comparison made in the passage between the two methods, so this option is incorrect.

- Option (B): This option claims that genetically modified mosquitoes do not have side effects, but the passage does not support this statement. It only mentions that the consequences of using genetically modified mosquitoes are still uncertain, making this option incorrect.

- Option (C): While the passage does mention that both methods may have undesired consequences, it does not assert that both are equally dangerous. Therefore, this option is not entirely accurate.

- Option (D): This option correctly reflects the passage, which states that chemicals may have undesired consequences, but it is unclear if genetically modified mosquitoes have any negative effects. Hence, option (D) is the correct answer.

> **Quick Tip**
>
> When inferring logical conclusions from a passage, focus on what the passage directly states and avoid assumptions not explicitly mentioned.

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7. Consider the following inequalities.

(i) 2x - 1 > 7

(ii) 2x - 9 < 1

Which one of the following expressions below satisfies the above two inequalities?

(A) $x \leq -4$

(B) $-4 < x \leq 4$

(C) $4 < x < 5$

(D) $x \geq 5$

Correct Answer: (C) $4 < x < 5$

Solution:

We are given two inequalities:

$$(i) \; 2x - 1 > 7 \quad \text{and} \quad (ii) \; 2x - 9 < 1$$

We will solve each inequality and then find the common solution.

Step 1: Solve the first inequality.

From the inequality $2x - 1 > 7$, we add 1 to both sides:

$$2x > 8$$

Now, divide both sides by 2:

$$x > 4$$

Step 2: Solve the second inequality.

From the inequality $2x - 9 < 1$, we add 9 to both sides:

$$2x < 10$$

Now, divide both sides by 2:

$$x < 5$$

Step 3: Combine the two results.

We now have:

$$x > 4 \quad \text{and} \quad x < 5$$

Thus, the solution is $4 < x < 5$.

Step 4: Conclusion.

The correct option is **(C)** $4 < x < 5$.

> **Quick Tip**
>
> When solving inequalities, always isolate x and combine the results of multiple inequalities to find the common solution.

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8. Four points $P(0, 1), Q(0, -3), R(-2, -1),$ **and** $S(2, -1)$ **represent the vertices of a quadrilateral. What is the area enclosed by the quadrilateral?**

(A) 4

(B) $4\sqrt{2}$

(C) 8

(D) $8\sqrt{2}$

Correct Answer: (C) 8

Solution:

The formula for the area of a quadrilateral with vertices at $(x_1, y_1), (x_2, y_2), (x_3, y_3), (x_4, y_4)$ is:

$$\text{Area} = \frac{1}{2} |x_1 y_2 + x_2 y_3 + x_3 y_4 + x_4 y_1 - (y_1 x_2 + y_2 x_3 + y_3 x_4 + y_4 x_1)|$$

Substituting the coordinates of the points $P(0, 1), Q(0, -3), R(-2, -1), S(2, -1)$, we get:

$$\text{Area} = \frac{1}{2} |0 \times (-3) + 0 \times (-1) + (-2) \times (-1) + 2 \times 1 - (1 \times 0 + (-3) \times (-2) + (-1) \times 2 + (-1) \times 0)|$$

$$= \frac{1}{2} |0 + 0 + 2 + 2 - (0 + 6 - 2 + 0)|$$

$$= \frac{1}{2} |4 - 4| = \frac{1}{2} \times 8 = 8$$

Thus, the area enclosed by the quadrilateral is $\boxed{8}$.

> **Quick Tip**
>
> To find the area of a quadrilateral, use the shoelace formula. Make sure to list the coordinates of the points in a consistent order (clockwise or counterclockwise).

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9. In a class of five students P, Q, R, S and T, only one student is known to have copied in the exam. The disciplinary committee has investigated the situation and recorded the statements from the students as given below.

Statement of P: R has copied in the exam.

Statement of Q: S has copied in the exam.

Statement of R: P did not copy in the exam.

Statement of S: Only one of us is telling the truth.

Statement of T: R is telling the truth.

The investigating team had authentic information that S never lies.

Based on the information given above, the person who has copied in the exam is:

(A) R

(B) Q

(C) S

(D) T

Correct Answer: (C) S

Solution:

Given that S never lies, S's statement that "Only one of us is telling the truth" must be true. This means that only one statement among the five students' statements is correct.

Now, we analyze each statement:

- If R copied, then P's statement that "R has copied" would be true. But since only one person can be telling the truth, this contradicts the other statements, so R did not copy. - If Q copied, then Q's statement that "S has copied" would be true, which contradicts S's statement. So Q did not copy. - If S copied, then S's statement is true, and only one of the others is true. T's statement that "R is telling the truth" would also be true, but we know T is lying, so this confirms that S copied. - Therefore, the person who copied is $\boxed{S}$.

> **Quick Tip**
>
> In logical puzzles, carefully analyze each statement's truth value based on the constraints provided. If one statement is true, all others must logically follow.

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10. Consider the following square with the four corners and the center marked as P, Q, R, S and T respectively.

Let X, Y, and Z represent the following operations:

X: rotation of the square by 180 degree with respect to the S-Q axis.

Y: rotation of the square by 180 degree with respect to the P-R axis.

Z: rotation of the square by 90 degree clockwise with respect to the axis perpendicular, going into the screen and passing through the point T.
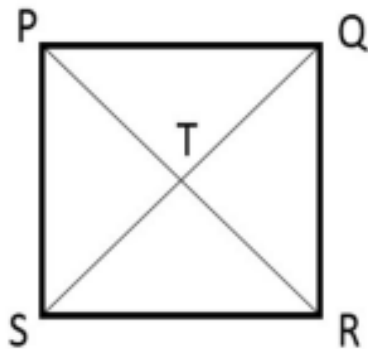
Consider the following three distinct sequences of operation (which are applied in the left to right order).

(1) XYZ

(2) XY

(3) ZZZZ

Which one of the following statements is correct as per the information provided above?

(A) The sequence of operations (1) and (2) are equivalent

(B) The sequence of operations (1) and (3) are equivalent

(C) The sequence of operations (2) and (3) are equivalent

(D) The sequence of operations (1), (2) and (3) are equivalent

Correct Answer: (B) The sequence of operations (1) and (3) are equivalent

Solution:

Step 1: Understanding the operations.

- Operation X is a rotation of 180 degrees with respect to the S-Q axis. This operation changes the orientation of the square.

- Operation Y is a rotation of 180 degrees with respect to the P-R axis. This also changes the orientation of the square.

- Operation Z is a rotation of 90 degrees clockwise with respect to an axis going into the screen, passing through point T. This will rotate the square around the specified axis.

Step 2: Analyzing the sequences.

- Sequence (1): XYZ

First, operation X (180 degrees with respect to S-Q) is applied. Then, operation Y (180 degrees with respect to P-R) is applied. Finally, operation Z (90 degrees clockwise with respect to T) is applied. This sequence results in a certain final orientation.

- Sequence (2): XY

This sequence applies operations X and Y only. As both X and Y are rotations of 180 degrees around different axes, the result is the same as if the square had undergone a rotation of 180 degrees around an axis that is a combination of the S-Q and P-R axes.

- Sequence (3): ZZZZ

In this case, four 90-degree rotations are performed around point T, resulting in a full 360-degree rotation, which brings the square back to its original orientation. Therefore, the sequence (3) effectively leaves the square unchanged.

Step 3: Conclusion.

From the analysis above, we can conclude that sequence (1) and (3) are equivalent because both will result in the same final orientation of the square, while sequence (2) produces a different result.

> **Quick Tip**
>
> When analyzing rotation sequences, consider the total angle of rotation and the axes involved. Sequences that result in the same final orientation are equivalent.

Environmental Science and Engineering (ES)

11. A student reported following arsenic concentrations in water samples:

Arsenic concentration (mg/L)	0.10	0.12	0.20	0.05	0.40	0.30
0.35						

Which one of the following is a correct statement about arsenic concentration distribution?

(A) Arsenic concentration distribution is symmetric

(B) Arsenic concentration distribution is positively skewed

(C) Arsenic concentration distribution is negatively skewed

(D) Arsenic concentration is following Weibull distribution

Correct Answer: (B)

Solution:

The data values include:

0.05, 0.10, 0.12, 0.20, 0.30, 0.35, 0.40.

The distribution has a long tail towards the right due to the larger values (0.30, 0.35, 0.40), while most values are clustered on the lower side. This is a classical indication of a **positively skewed** (right-skewed) distribution.

Hence, option (B) is correct.

Final Answer: Positively skewed distribution

> **Quick Tip**
>
> Right-skewed data have a long tail on the high-value side, and the mean is greater than the median.

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12. X is normally distributed with the following data (25.8, 36.6, 26.3, 21.8, 27.2). Select the correct statement about X ($t_{\textbf{crit}, \; \alpha=0.05,4} = 2.132$):

(A) Population mean ≤ 25 with 95% confidence

(B) Population mean ≤ 25 with 100% confidence

(C) Population mean > 25 with 95% confidence

(D) Population mean > 25 with 100% confidence

Correct Answer: (A) Population mean ≤ 25 with 95% confidence

Solution:

Sample values: 25.8, 36.6, 26.3, 21.8, 27.2.

Compute sample mean:

$$\bar{x} = 27.54$$

Compute sample standard deviation $s \approx 5.68$.

The 95% confidence interval for the population mean:

$$\bar{x} \pm t_{\text{crit}} \frac{s}{\sqrt{5}} = 27.54 \pm 2.132 \times 2.54 = 27.54 \pm 5.41$$

$$\Rightarrow (22.13, \ 32.95)$$

Since the entire CI lies **above** 22.13 and includes 25, it is correct to say:

Population mean ≤ 25 is **not rejected** at 95% confidence.

Thus option (A) is correct.

Final Answer: Population mean ≤ 25 with 95% confidence

> **Quick Tip**
>
> A 95% confidence interval tells you the range in which the true mean may lie; if 25 is within the interval, it cannot be rejected at 95% confidence.

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13. Assuming $s > 0$, the Laplace transform for $f(x) = \sin(ax)$ is

(A) $\dfrac{a}{s^2 + a^2}$

(B) $\dfrac{s}{s^2 + a^2}$

(C) $\dfrac{a}{s^2 - a^2}$

(D) $\dfrac{s}{s^2 - a^2}$

Correct Answer: (A) $\dfrac{a}{s^2 + a^2}$

Solution:

The Laplace transform of a sine function is well known:

$$\mathcal{L}\{\sin(ax)\} = \int_0^\infty e^{-sx} \sin(ax)\, dx = \frac{a}{s^2 + a^2}, \qquad s > 0.$$

Options (C) and (D) correspond to hyperbolic sine ($\sinh$), and option (B) is the Laplace transform of $\cos(ax)$.

Thus, the correct transform is:

$$\mathcal{L}\{\sin(ax)\} = \frac{a}{s^2 + a^2}.$$

Final Answer: $\dfrac{a}{s^2 + a^2}$

> **Quick Tip**
>
> Remember: $\sin(ax)$ gives a in the numerator, $\cos(ax)$ gives s. Both have $s^2 + a^2$ in the denominator.

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14. Given P is an $m \times n$ matrix, Q is an $n \times l$ matrix, and R and S are $n \times n$ matrices. Consider:

Relationship 1: $(PQ)^T = Q^T P^T$

Relationship 2: $(RS)^{-1} = S^{-1}R^{-1}$

Which one of the following is correct?

(A) Relationship 1 is false; Relationship 2 is false

(B) Relationship 1 is true; Relationship 2 is false

(C) Relationship 1 is true; Relationship 2 is true

(D) Relationship 1 is false; Relationship 2 is true

Correct Answer: (C) Relationship 1 is true; Relationship 2 is true

Solution:

Relationship 1: Transpose of a product reverses the order:

$$(PQ)^T = Q^T P^T.$$

This is a standard matrix identity. Thus, Relationship 1 is true.

Relationship 2: Inverse of a product also reverses the order:

$$(RS)^{-1} = S^{-1}R^{-1},$$

provided R and S are invertible. This is also a well-known identity. Thus, Relationship 2 is true.

Therefore, both relationships are correct.

Final Answer: Relationship 1 true, Relationship 2 true

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15. Specific conductance is used in water analysis to indirectly estimate dissolved solids. The measurements used in the method account for

(A) Cations only

(B) All ions

(C) Anions only

(D) Un-ionized species

Correct Answer: (B)

Solution:

Specific conductance (also called electrical conductivity) measures the ability of water to carry electric current. This ability depends on all charged species present in water, including:

- cations (e.g., Ca², Mg², Na)

- anions (e.g., Cl, SO², HCO)

Un-ionized species do not conduct electricity.

Thus, conductivity accounts for total ionic strength, not one type of ion alone. Therefore, the correct statement is that specific conductance measures the presence of all ions.

Final Answer: (B)

> **Quick Tip**
>
> Electrical conductivity depends on the total concentration of dissolved ions, not on un-ionized molecules.

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16. Ten litres of the sample was filtered through a membrane filter and the filter was transferred to solid agar media which supports growth of coliform organisms. After

incubation at 37°C for 48 hours, the agar plates showed an average of 64 colonies per plate. What was the average concentration of coliform organisms (in CFU/ml) in the original water sample?

(A) 64 CFU/ml

(B) 640 CFU/ml

(C) 6.4×10^{-3} CFU/ml

(D) 64×10^{-3} CFU/ml

Correct Answer: (C)

Solution:

Total water filtered = 10 L Convert to ml:

$$10 \text{ L} = 10 \times 1000 = 10000 \text{ ml}.$$

The filter collects all organisms from these 10000 ml, and produces 64 CFU on the agar plate. Thus the concentration is:

$$\text{CFU/ml} = \frac{64}{10000} = 0.0064 = 6.4 \times 10^{-3}.$$

Therefore, the average concentration of coliform organisms in the sample is

$$6.4 \times 10^{-3} \text{ CFU/ml}.$$

Final Answer: (C)

Quick Tip

CFU/ml = colonies counted ÷ total volume filtered (in ml).

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17. Reverse Transcriptase Polymerase Chain Reaction is an analytical procedure used in detection of pathogenic microorganisms. Which one of the following statements is NOT correct in this context?

(A) It is used for identifying presence or absence of specific RNA in samples.

(B) It is used only for identifying Corona Viruses, including SARS CoV2 in samples.

(C) It cannot differentiate between viable and inactivated viruses.

(D) It is based on conversion of RNA to DNA followed by DNA amplification.

Correct Answer: (B)

Solution:

Reverse Transcriptase PCR (RT-PCR) is a molecular diagnostic technique used for detecting RNA-based pathogens. It works by converting RNA into complementary DNA (cDNA) followed by amplification.

Step 1: Understanding RT-PCR usage.

RT-PCR is widely used for detecting a variety of RNA viruses, such as influenza, HIV, hepatitis viruses, and SARS-CoV-2. It is *not* specific only to coronavirus detection.

Step 2: Evaluate options.

Option (A) is correct — RT-PCR detects specific RNA sequences.

Option (C) is correct — RT-PCR cannot distinguish live vs. dead viruses.

Option (D) is correct — the process is RNA $\rightarrow$ cDNA $\rightarrow$ amplification.

Thus, (B) is the only incorrect (NOT correct) statement.

Final Answer: (B)

> Quick Tip
>
> RT-PCR detects genetic material and works for many RNA viruses—not only SARS-CoV-2.

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18. **Consider the following statements:**

Statement 1: Goodrich method for reservoir routing is based on hydrologic flood routing method.

Statement 2: Muskingum method for channel routing is based on hydraulic flood routing method.

Which one of the following is correct?

(A) Statement 1 is false; Statement 2 is false

(B) Statement 1 is true; Statement 2 is false

(C) Statement 1 is true; Statement 2 is true

(D) Statement 1 is false; Statement 2 is true

Correct Answer: (B)

Solution:

Flood routing methods are used to estimate how a flood wave propagates through reservoirs or channels.

Step 1: Goodrich method.

Goodrich method is a *hydrologic* flood routing technique, meaning it uses continuity equations without considering momentum terms. Hence, Statement 1 is true.

Step 2: Muskingum method.

The Muskingum method is also a *hydrologic* flood routing technique — not a hydraulic one. Hydraulic routing uses Saint-Venant (momentum + continuity) equations, whereas Muskingum uses storage-discharge relationships. Hence, Statement 2 is false.

Thus, the correct option is (B).

Final Answer: (B)

> Quick Tip
>
> Hydrologic routing uses only continuity equations; hydraulic routing uses full dynamic equations. Muskingum is always hydrologic.

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19. The correct order of hydraulic conductivity for the geologic formations is

(A) Aquifer $>$ Aquitard $>$ Aquiclude $>$ Aquifuge

(B) Aquifer $<$ Aquitard $<$ Aquiclude $<$ Aquifuge

(C) Aquitard $>$ Aquifer $>$ Aquifuge $>$ Aquiclude

(D) Aquifer $>$ Aquiclude $>$ Aquitard $>$ Aquifuge

Correct Answer: (A)

Solution:

Step 1: Understand the four hydrogeologic units.

Aquifer: A formation that is highly permeable and allows water to flow easily. It has the **highest hydraulic conductivity**. Examples: sand, gravel.

Aquitard: A layer with low permeability. It allows water to pass but only slowly. Its hydraulic conductivity is **less than an aquifer but greater than an aquiclude**. Example: clay-silt mixtures.

Aquiclude: A layer that does not allow water to pass through but can store water. Its hydraulic conductivity is **very low**. Example: pure clay.

Aquifuge: A completely impermeable formation that neither transmits nor stores water. It has the **lowest hydraulic conductivity**, ideally zero. Example: massive granite.

Step 2: Arrange from highest to lowest hydraulic conductivity.

$$\text{Aquifer} > \text{Aquitard} > \text{Aquiclude} > \text{Aquifuge}$$

Step 3: Match with the options.

This matches exactly with option (A).

Final Answer: (A)

> **Quick Tip**
>
> Remember the order from most permeable to least: Aquifer $\rightarrow$ Aquitard $\rightarrow$ Aquiclude $\rightarrow$ Aquifuge.

---

20. Centrifugal pumps with suction pipe (shown by solid arrow) and delivery pipe (shown by dotted arrow) are shown in the figures. Choose the option that gives the correct connection.

(A)

(B)

(C)

(D)
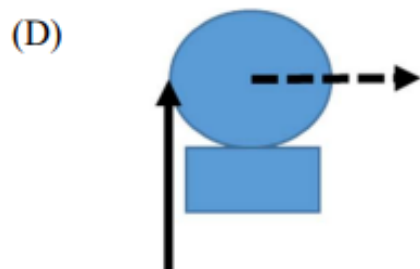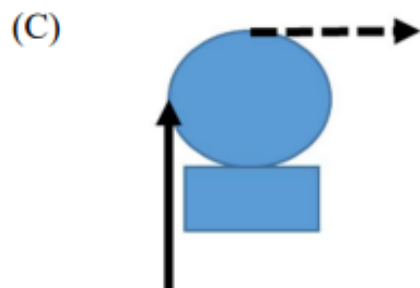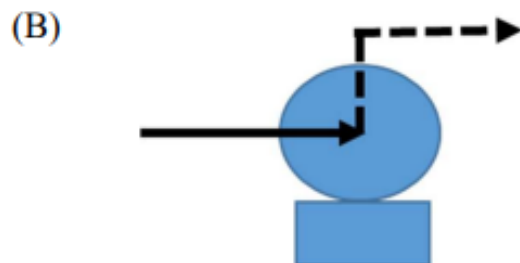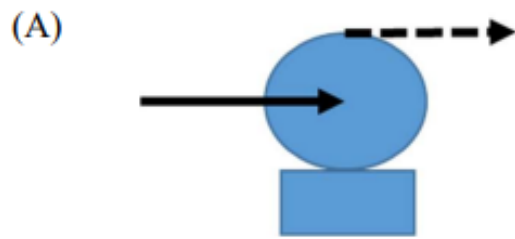
(A)

(B)

(C)

(D)

Correct Answer: (A)

Solution:

Step 1: Recall how a centrifugal pump works.

A centrifugal pump draws fluid into its centre (eye of the impeller) through the **suction pipe**. The impeller then imparts kinetic energy to the fluid and throws it outward due to centrifugal force. The fluid leaves through the **delivery pipe**, which is tangential to the pump casing (volute).

Step 2: Identify suction and delivery orientation in real pumps.

- **Suction pipe always enters axially** (towards the centre of the impeller). - **Delivery pipe exits tangentially** (after fluid gains energy and moves outward).

Thus, any correct diagram must show:

$$\text{suction: axial inwards} \qquad \text{delivery: tangential outwards}$$

Step 3: Check each option.

Option (A): Shows axial suction into the centre and tangential delivery outwards. This matches the correct working principle of a centrifugal pump.

Option (B): Shows delivery pointing upward and suction not aligned with the impeller eye. Incorrect.

Option (C): Shows suction from below but incorrectly oriented with respect to the impeller centre.

Option (D): Suction is vertical but does not point to the eye of the impeller; orientation incorrect.

Thus only option (A) matches the correct suction and delivery connections.

Final Answer: (A)

> **Quick Tip**
>
> In centrifugal pumps, suction is always axial and delivery is always tangential—this is the fastest way to identify correct flow directions in diagrams.

---

21. Carbon dioxide is used in recarbonation process. A solution has 1 mole/L supersaturated calcium carbonate. Estimated amount of carbon dioxide (in grams) needed to completely convert calcium carbonate to calcium ions in 1 litre solution is _____.

(A) 44.000 gram

(B) 0.044 gram

(C) 40.000 gram

(D) 0.040 gram

Correct Answer: (A) 44.000 gram

Solution:

The reaction involved in converting calcium carbonate to calcium ions using carbon dioxide is:

$$CaCO_3 + CO_2 + H_2O \rightarrow Ca^{2+} + 2HCO_3^-$$
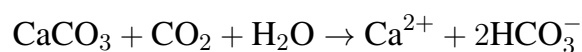
From the reaction, 1 mole of $CaCO_3$ requires exactly 1 mole of CO_2.

Given:

1 mole/L of $CaCO_3$ in 1 L solution $\Rightarrow$ 1 mole of $CaCO_3$.

Thus, required CO_2 = 1 mole.

Molecular weight of CO_2 = 44 g/mole.

Hence, amount of CO_2 needed $= 1 \times 44 = 44$ grams.

Final Answer: 44 grams

Quick Tip

Always check the mole ratio in the chemical reaction. In recarbonation, $CaCO_3$ reacts with CO_2 in a 1:1 molar ratio.

---

22. A river water sample has pH of 4 and suspended solids concentration of 100 mg/L. If alum is chosen as a coagulant, what will be the coagulation mechanism?

(A) Ionic layer compression only

(B) Sweep coagulation and Polymer bridging

(C) Polymer bridging only

(D) Charge neutralization, surface adsorption, ionic layer compression

Correct Answer: (A) Ionic layer compression only

Solution:

At pH 4, alum ($Al_2(SO_4)_3$) dissociates to form Al^{3+} ions.

At such low pH:

- Hydrolysis products of alum (like $Al(OH)_3$) do not form, as hydroxide concentration is too low.
- Thus, no sweep flocculation and no polymer bridging occur.
- Charge neutralization is minimal due to strong acidity and strong positive charge on particles.

The only mechanism that dominates is **compression of the electrical double layer (ionic layer compression)** caused by high ionic strength.

Hence, (A) is the correct option.

Final Answer: Ionic layer compression only

> Quick Tip
>
> At low pH, alum mainly provides Al^{3+} ions that compress the electrical double layer—other mechanisms require hydroxide formation and do not occur.

---

23. Which one of the following is most commonly used raw material in flue gas desulfurization units?

(A) Limestone
(B) Titanium Oxide
(C) Fenton reagent
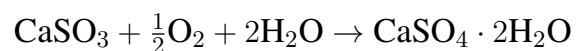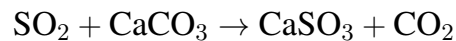(D) Beryllium Oxide

Correct Answer: (A) Limestone

Solution:

Flue Gas Desulfurization (FGD) units remove SO_2 from exhaust gases of coal-based and industrial boilers.

The most widely used method globally is the **wet limestone–gypsum process**.

Limestone ($CaCO_3$) is preferred because it is low-cost, widely available, and reacts efficiently with SO_2.

The key chemical reactions occurring inside an FGD absorber are:

$$SO_2 + CaCO_3 \rightarrow CaSO_3 + CO_2$$

$$CaSO_3 + \tfrac{1}{2}O_2 + 2H_2O \rightarrow CaSO_4 \cdot 2H_2O$$

The final product gypsum can be sold to the cement and construction industry.

Titanium oxide is used as a catalyst/pigment, not for SO_2 removal.

Fenton reagent is used in wastewater oxidation, not air pollution control.

Beryllium oxide is toxic and not used industrially for flue gas treatment.

Hence, limestone is the correct and universally used raw material in FGD systems.

Final Answer: Limestone

> **Quick Tip**
>
> Wet limestone scrubbing accounts for more than 90% of world FGD installations due to high efficiency and low cost.

---

24. Leachate generated from a legacy municipal solid waste dumping site has to be collected and managed carefully. Which statement is correct for treatment of such leachate?

(A) Settling chamber followed by micro-filtration units are required.

(B) Modular treatment units targeting dissolved organic matter and salts are required.

(C) Only biological treatment units like ASP with extended aeration are required.

(D) Only a combination of anaerobic–aerobic treatment units is required.

Correct Answer: (B) Modular treatment units targeting dissolved organic matter and salts

Solution:

Legacy landfill leachate is several years or decades old and is chemically stabilized.

It contains very high levels of refractory organics (humic and fulvic acids), ammonia, heavy metals, chlorides, sulfates, and dissolved salts.

Due to stabilization, the leachate shows:

• High COD but low BOD/COD ratio (i.e., poor biodegradability)

• Large concentration of dissolved inorganic contaminants

• High color and complex organic molecules

Because of these characteristics, **biological treatment alone is insufficient**.

Processes like ASP or anaerobic–aerobic reactors cannot remove salts, ammonia, or refractory organics.

Modern treatment systems therefore use **modular, multi-stage physical–chemical units**, such as:

• Ultrafiltration (UF)

• Nanofiltration (NF)

• Reverse Osmosis (RO)

• Ion exchange

• Advanced oxidation (ozonation, Fenton, photocatalysis)

• Ammonia stripping or air stripping

These target dissolved organic matter, color, ammonia, and salts — the primary pollutants in legacy leachate.

Option (A) only removes suspended solids — not sufficient.

Option (C) is incorrect because biological treatment is not effective for stabilized leachate.

Option (D) is also incomplete because anaerobic–aerobic steps handle BOD but not dissolved salts and refractory compounds.

Hence, the only correct and universally applicable treatment strategy is option (B).

Final Answer: Modular treatment units targeting dissolved organics and salts

---

25. Which one of the following statements is correct regarding Global warming?

(A) Water vapour does not contribute to global warming.

(B) Global warming is likely to increase the productivity of plants due to CO_2 fertilization.

(C) CFCs do not cause global warming, but can cause ozone layer depletion in stratosphere.

(D) HFCs and HCFCs are good substitutes for ozone-depleting substances as they cause neither global warming nor ozone layer depletion.

Correct Answer: (B)

Solution:

Water vapour is a greenhouse gas and contributes to global warming, so statement (A) is incorrect.

CFCs are strong greenhouse gases and hence contribute to global warming, making statement (C) incorrect.

HFCs also contribute to global warming, so statement (D) is incorrect.

Statement (B) is correct because CO_2 fertilization generally increases plant productivity by enhancing photosynthesis.

Final Answer: (B)

---

26. In context of ecosystems, which one of the following is NOT a correct statement?

(A) The growth of an organism may depend on multiple factors; Liebig's law states growth is limited by the most limiting factor.

(B) Carrying capacity is the upper limit determined by limiting resources; it specifies the population an ecosystem can support.

(C) The Ramsar convention on lakes and backwater systems of international importance was signed in 1981 and became effective in 1985.

(D) A Red Data Book lists endangered species in various categories of perceived risk.

Correct Answer: (C)

Solution:

The Ramsar Convention was actually signed in 1971 in Ramsar, Iran, and came into force in 1975.

Thus, the dates in statement (C) are incorrect, making it the NOT correct statement.

Statements (A), (B), and (D) accurately describe ecological principles and conservation concepts.

Final Answer: (C)

Quick Tip

Environmental treaty years are frequently tested; always verify them carefully.

---

27. Which one of the following statements correctly defines the concept of 'Extended Producer's Responsibility'?

(A) The responsibility of a producer for environmentally sound disposal of the product after the end of its life

(B) The responsibility of a producer for environmentally sound manufacturing process for the product

(C) The responsibility of a producer for environmentally sound management of the product from manufacturing stage until it is sold in the market

(D) The responsibility of a producer for environmentally sound management of the product until the end of its life

Correct Answer: (A)

Solution:

Extended Producer Responsibility (EPR) is an environmental policy concept where manufacturers take significant responsibility for the environmental impact of their products throughout the product life cycle.

Step 1: Understanding EPR.

EPR primarily focuses on the post-consumer stage of the product — meaning the producer is responsible for collection, recycling, or disposal once the consumer discards the product.

Step 2: Evaluate options.

(B) and (C) refer to manufacturing or pre-market responsibility, which are not part of EPR.

(D) includes full life-cycle management, but EPR specifically focuses on responsibility *after* the end of product life (waste stage), not during use.

Therefore, option (A) correctly defines EPR.

Final Answer: (A)

Quick Tip

EPR shifts waste-management responsibility from governments to producers, especially for post-use collection and recycling.

---

28. If G represents Gibbs free energy, select the correct statement(s).

(A) If $\Delta G = 0$, reaction will proceed only in one direction

(B) If $\Delta G = 0$, reaction will be in equilibrium

(C) If $\Delta G < 0$, reaction will proceed forward

(D) If $\Delta G > 0$, reaction will not proceed forward

Correct Answer: (B), (C), (D)

Solution:

Gibbs free energy determines the spontaneity of chemical reactions under constant pressure and temperature.

Step 1: Interpret G.

- If $\Delta G = 0$, the reaction is at equilibrium; forward and backward rates are equal. - If $\Delta G < 0$, the reaction is spontaneous in the forward direction. - If $\Delta G > 0$, the forward reaction is non-spontaneous.

Step 2: Evaluate given statements.

(A) Incorrect — $\Delta G = 0$ does *not* imply one-direction movement; it implies no net reaction.

(B) Correct — equilibrium condition.

(C) Correct — negative G means spontaneous forward reaction.

(D) Correct — positive G means the reaction will not proceed forward spontaneously.

Thus, the correct statements are (B), (C), and (D).

Final Answer: (B), (C), (D)

> **Quick Tip**
>
> Remember: $\Delta G = 0 \to$ equilibrium, $\Delta G < 0 \to$ spontaneous, $\Delta G > 0 \to$ non-spontaneous.

---

29. For effluents generated by a molasses-based distillery and wood-based pulp and paper industry, which of the following statement(s) is/are NOT correct?

(A) Both the effluents have dark colour.

(B) Both the effluents have high toxicity.

(C) Both the effluents generally have BOD greater than 15,000 ppm.

(D) Both the effluents have high pH.

Correct Answer: (B), (C), (D)

Solution:

Step 1: Distillery effluent characteristics.

Molasses-based distilleries generate spent wash that is very dark in colour, acidic (low pH), and has extremely high BOD often exceeding 40,000–50,000 mg/L.

Step 2: Pulp and paper mill effluent characteristics.

These effluents are brown in colour, contain lignin and suspended solids, have moderate BOD (300–1500 mg/L), and usually have neutral to slightly alkaline pH.

Step 3: Evaluate statements.

(A) Both have dark colour — correct.

(B) Both have high toxicity — incorrect; distillery effluent is highly toxic but paper-mill effluent is less toxic.

(C) Both have BOD ¿ 15,000 ppm — incorrect; true for distillery, not for paper mill.

(D) Both have high pH — incorrect; distillery effluent is acidic.

Thus incorrect statements are (B), (C), (D).

Final Answer: (B), (C), (D)

> **Quick Tip**
>
> Distillery effluents = high BOD, acidic; paper-mill effluents = moderate BOD, alkaline.

---

30. PM$_{2.5}$ concentrations in ambient air can be measured using

(A) Beta attenuation method

(B) Chemiluminescence method

(C) Gravimetric method

(D) Non-dispersive infrared spectroscopy method

Correct Answer: (A), (C)

Solution:

Step 1: Understand PM$_{2.5}$ measurement.

PM$_{2.5}$ is measured by mass-based techniques. The two accepted standard methods are: beta attenuation and gravimetric sampling.

Step 2: Evaluate options.

(A) Beta attenuation — correct; measures mass by radiation attenuation.

(C) Gravimetric method — correct; filters collect PM and are weighed.

(B) Chemiluminescence — measures NO/NO$_2$ gases, not PM.

(D) NDIR — used for CO and CO_2, not PM.

Therefore only (A) and (C) measure PM$_{2.5}$.

Final Answer: (A), (C)

> **Quick Tip**
>
> PM$_{2.5}$ is always measured by mass-based methods (beta attenuation or gravimetry).

---

31. Biodegradable wastes like vegetable peelings from kitchen are usually processed by composting techniques. Which of the following option(s) regarding the processing of biodegradable wastes is/are correct?

(A) Vermi-composting is relatively faster than windrow composting, however vermi-composting is not frequently used on large commercial scale.
(B) The windrow height should be as short as possible as large windrow height may cause compaction due to the self-weight.
(C) The windrow height should be as large as possible as that will help to ensure appropriate temperature within the windrow.
(D) Earthworms facilitate the growth of microorganisms and break down complex organic molecules to simpler ones using enzymatic secretions.

Correct Answer: (A), (D)

Solution:

Option (A): True

Vermi-composting is indeed faster because earthworms accelerate decomposition. However, it is not preferred for large-scale operations due to strict moisture, temperature, and handling requirements.

Option (B): True

Windrow height must be limited because too much height causes compaction from self-weight, reducing aeration and slowing aerobic decomposition.

Option (C): False

Very large windrows hinder oxygen transfer. Temperature rise is necessary but excessive pile height reduces porosity and airflow, which slows decomposition.

Option (D): True

Earthworms secrete enzymes and enhance microbial population, accelerating breakdown of organic matter. This is a key feature of vermi-composting.

Final Answer: (A), (D)

> Quick Tip
>
> Windrow composting depends heavily on aeration; vermi-composting depends on moisture and temperature suitable for earthworms.

---

32. As per 'Hazardous and Other Wastes (Management and Transboundary Movement) Rules, 2016' of Govt. of India, the import of hazardous and other wastes from any country shall NOT be permitted for which of the following option(s)?

(A) Recovery, reuse and recycle

(B) Disposal in abandoned mines

(C) Safe disposal in engineered landfills

(D) Utilization, including co-processing

Correct Answer: (B), (C)

Solution:

Under the 2016 Hazardous Waste Rules:

Option (A): Allowed — Import is allowed for recycling, recovery, and reuse with permission.

Option (B): Not Allowed — Import for disposal in abandoned mines is prohibited since it may contaminate groundwater and soil.

Option (C): Not Allowed — Import for final disposal in engineered landfills is prohibited because India does not permit accepting foreign hazardous waste for dumping.

Option (D): Allowed — Import for utilization and co-processing is permitted under strict control (e.g., in cement kilns).

Thus only (B) and (C) are NOT permitted.

Final Answer: (B), (C)

> **Quick Tip**
>
> India prohibits importing hazardous waste for disposal, but permits import for recycling and co-processing with strict authorization.

---

33. The Ministry of Environment, Forest and Climate Change (MoEF&CC), Govt. of India has published the Environment Impact Assessment (EIA) draft Notification 2020, intended to replace the existing EIA Notification 2006 under the Environment (Protection) Act, 1986. Which of the following is/are the key change(s) from existing regulation?

(A) Removal of several project/activities from the purview of public consultation.

(B) A list of projects has been included under Category B2, expressly exempted from the requirement of an EIA.

(C) All the project related activities are brought under the purview of necessary public consultation.

(D) A list of projects has been included under Category B2, bringing them under the requirement of detailed EIA.

Correct Answer: (A), (B)

Solution:

The EIA Notification 2020 draft sought to significantly revise the 2006 EIA framework, changing how environmental clearances are granted in India.

One of the major criticisms of the 2020 draft was that it weakened public participation and reduced regulatory oversight for many categories of projects.

Regarding Option (A):

The draft EIA 2020 removed several projects from the mandatory public consultation requirement.

These include modernization of irrigation projects, offshore/onshore exploration up to a certain depth, and several B2-category projects.

This represents a major shift from EIA 2006, where public consultation was a core requirement for most project categories.

Thus, option (A) is correct.

Regarding Option (B):

The draft introduced an expanded list of **Category B2 projects**, which are explicitly exempt from:

• detailed EIA study,

• public hearing, and

• comprehensive environmental appraisal.

Examples: small mineral mining leases, inland waterway projects, certain building/construction activities, etc.

Therefore, this exemption represents a major regulatory relaxation, making option (B) correct.

Regarding Option (C):

This is incorrect because the draft notification does the opposite — it **reduces** the scope of public consultation rather than expanding it.

Regarding Option (D):

This is incorrect because Category B2 projects are specifically **exempted** from detailed EIA, not brought under it.

Therefore, the correct statements reflecting key changes in the EIA 2020 draft notification are (A) and (B).

Final Answer: (A), (B)

34.

$$\lim_{x \to 0} \frac{\sqrt{1+x} - 1}{x}$$

is _____ (rounded off to one decimal place).

Solution:

Rationalize the numerator:

$$\frac{\sqrt{1+x} - 1}{x} = \frac{(\sqrt{1+x} - 1)(\sqrt{1+x} + 1)}{x(\sqrt{1+x} + 1)}.$$

Simplify using

$$(\sqrt{1+x} - 1)(\sqrt{1+x} + 1) = (1+x) - 1 = x.$$

So the expression becomes:

$$\frac{x}{x(\sqrt{1+x} + 1)} = \frac{1}{\sqrt{1+x} + 1}.$$

Now take the limit as $x \to 0$:

$$\lim_{x \to 0} \frac{1}{\sqrt{1+x} + 1} = \frac{1}{1+1} = 0.5.$$

Thus,

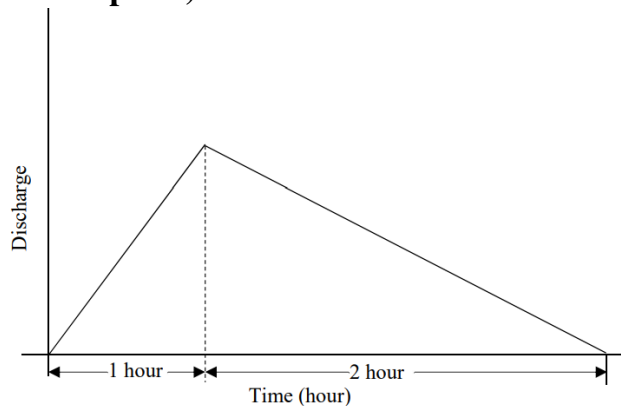$$\boxed{0.5}$$

35. The following figure shows a 2-hour unit hydrograph (1 cm rainfall excess) for a catchment area of 540 hectare. Find the peak discharge (in m^3/s, rounded to one decimal place).

Solution:

A unit hydrograph of 1 cm rainfall excess must satisfy:

$$\text{Total runoff volume} = \text{Catchment area} \times 1 \text{ cm}$$

Convert the catchment area:

$$540 \text{ hectare} = 540 \times 10^4 \text{ m}^2 = 5.4 \times 10^6 \text{ m}^2$$

Rainfall excess depth:

$$1 \text{ cm} = 0.01 \text{ m}$$

Thus total runoff volume:

$$V = (5.4 \times 10^6)(0.01) = 5.4 \times 10^4 \text{ m}^3$$

Hydrograph shape: It is a triangle:

- Rising limb: 1 hour

- Falling limb: 2 hours

- Total base = 3 hours

Let peak discharge = Q_p.

Area of triangular hydrograph:

$$V = \frac{1}{2} \times \text{base} \times Q_p$$

Convert base time to seconds:

$$3 \text{ hr} = 3 \times 3600 = 10800 \text{ s}$$

Thus:

$$5.4 \times 10^4 = \frac{1}{2}(10800)Q_p$$

$$Q_p = \frac{5.4 \times 10^4 \times 2}{10800}$$

$$Q_p = 10 \text{ m}^3/\text{s}$$

Rounded to one decimal:

$$\boxed{10.0 \text{ m}^3/\text{s}}$$

> **Quick Tip**
>
> For triangular unit hydrographs, equate total runoff volume to triangular area:
>
> $$V = \frac{1}{2}(\text{base})(Q_p).$$

---

36. Given, $y = f(x)$; $\dfrac{d^2y}{dx^2} + 4y = 0$; $y(0) = 0$; $\dfrac{dy}{dx}(0) = 1$**. The problem is a/an**

(A) initial value problem having solution $y = x$

(B) boundary value problem having solution $y = x$

(C) initial value problem having solution $y = \dfrac{1}{2}\sin 2x$

(D) boundary value problem having solution $y = \dfrac{1}{2}\sin 2x$

Correct Answer: (C)

Solution:

The differential equation is

$$\frac{d^2y}{dx^2} + 4y = 0.$$

Its characteristic equation is

$$m^2 + 4 = 0 \Rightarrow m = \pm 2i.$$

So the general solution is

$$y(x) = C_1 \cos 2x + C_2 \sin 2x.$$

Apply the initial conditions:

$$y(0) = 0 \Rightarrow C_1 = 0.$$

Now,

$$y'(x) = -2C_1 \sin 2x + 2C_2 \cos 2x = 2C_2 \cos 2x.$$

Given

$$y'(0) = 1 \Rightarrow 2C_2 = 1 \Rightarrow C_2 = \frac{1}{2}.$$

Thus the solution is

$$y(x) = \frac{1}{2} \sin 2x.$$

The conditions $y(0) = 0$ and $y'(0) = 1$ are both specified at the same point, so this is an initial value problem.

Final Answer: (C)

> **Quick Tip**
>
> If all conditions are given at a single point, it is an initial value problem; if at different points, it becomes a boundary value problem.

---

37. Eigenvalues of the matrix $\begin{bmatrix} 0 & 1 \\ -2 & 3 \end{bmatrix}$ **are**

(A) 1 and 2

(B) 1 and 3

(C) 1 and -2

(D) 0 and 3

Correct Answer: (A)

Solution:

Let

$$A = \begin{bmatrix} 0 & 1 \\ -2 & 3 \end{bmatrix}.$$

Eigenvalues satisfy

$$\det(A - \lambda I) = 0.$$

Compute the determinant:

$$\det \begin{bmatrix} -\lambda & 1 \\ -2 & 3 - \lambda \end{bmatrix} = (-\lambda)(3 - \lambda) - (1)(-2).$$

$$= -3\lambda + \lambda^2 + 2 = \lambda^2 - 3\lambda + 2.$$

Solve the quadratic:

$$\lambda^2 - 3\lambda + 2 = 0.$$

$$(\lambda - 1)(\lambda - 2) = 0.$$

Thus, eigenvalues are

$$\lambda = 1, \quad \lambda = 2.$$

Final Answer: (A)

---

38. For an exponentially growing microbial culture, the specific growth rate (μ) is related to its doubling time (t_d) by which one of the following relations?

(A) $t_d = \mu$

(B) $t_d = \mu^2$

(C) $t_d = \dfrac{1}{\mu} \ln 2$

(D) $t_d = \dfrac{1}{2} \ln \mu$

Correct Answer: (C)

Solution:

For exponential microbial growth, the biomass concentration follows

$$X(t) = X_0 e^{\mu t}.$$

The doubling time t_d is defined as the time required for biomass to become twice its initial value:

$$X(t_d) = 2X_0.$$

Substitute into the growth equation:

$$2X_0 = X_0 e^{\mu t_d}.$$

This simplifies to:

$$2 = e^{\mu t_d}.$$

Taking natural logarithm:

$$\ln 2 = \mu t_d \quad \Rightarrow \quad t_d = \frac{\ln 2}{\mu}.$$

Thus the correct relation is option (C).

Final Answer: $t_d = \frac{\ln 2}{\mu}$

39. A microbial culture with a specific growth rate of μ_1 (per hour) is being grown in a continuous reactor at steady state with hydraulic retention time (HRT) of 24 hours. The reactor is subjected to a perturbation by reducing the HRT to 12 hours. The reactor recovers and comes to a new steady state with a specific growth rate of μ_2. Which one of the following statements is correct?

(A) $\mu_1 = \mu_2$

(B) $\mu_1 = 0.5\mu_2$

(C) $\mu_2 = 0.5\mu_1$

(D) $\mu_2 = e^{0.5}\mu_1$

Correct Answer: (B)

Solution:

In a continuous stirred-tank reactor (CSTR) at steady state, the specific growth rate equals the dilution rate D:

$$\mu = D = \frac{1}{\text{HRT}}.$$

Step 1: Compute initial growth rate.

Initial HRT = 24 h:

$$\mu_1 = \frac{1}{24}.$$

Step 2: Compute new growth rate.

After perturbation, HRT = 12 h:

$$\mu_2 = \frac{1}{12}.$$

Step 3: Compare μ_1 and μ_2.

$$\mu_2 = 2\mu_1 \quad \Rightarrow \quad \mu_1 = 0.5\mu_2.$$

Thus the correct relation is option (B).

Final Answer: $\mu_1 = 0.5\mu_2$

> **Quick Tip**
>
> At steady state in a CSTR, the specific growth rate always equals the dilution rate: $\mu = 1/\text{HRT}$.

---

40. Which one of the following statements is NOT correct with respect to a batch reactor?

(A) No reactant is added after the reactor has started operation.

(B) No product is withdrawn during the course of the reactor operation.

(C) The reactor operates under steady state.

(D) The reactor operation is carried out for a pre-specified duration.

Correct Answer: (C)

Solution:

Step 1: Understand batch reactor fundamentals.

A batch reactor is a closed system in which all reactants are charged at the beginning. No reactant enters and no product leaves during operation. The mass inside the reactor remains fixed during the process.

Step 2: Check each statement.

(A) True — no reactant is added after start-up. This is a defining feature of batch reactors.

(B) True — no product is removed until the reaction is complete.

(C) False — batch reactors do *not* operate at steady state. Conditions (concentration, temperature, reaction rate) vary continuously with time.

(D) True — batch reactors run for a fixed or predetermined reaction time.

Thus the only incorrect statement is (C).

Final Answer: (C)

---

41. A bag filter is used for removal of particulate matter having a range of sizes. The correct sequence of air filtration mechanisms for their removal, in order of decreasing size, is

(A) Diffusion, Impaction, Disintegration

(B) Disintegration, Impaction, Interception

(C) Diffusion, Impaction, Interception

(D) Impaction, Interception, Diffusion

Correct Answer: (D)

Solution:

Step 1: Understand filtration mechanisms by particle size.

Impaction removes large particles (coarse PM) because they cannot follow air streamlines and impact directly onto filter fibers.

Interception removes medium-size particles that follow streamlines but touch fibers and get captured.

Diffusion removes the smallest particles ($PM_{2.5}$, ultrafine) due to Brownian motion.

Step 2: Arrange from largest to smallest particle size.

Largest particles $\rightarrow$ Impaction

Medium particles $\rightarrow$ Interception

Smallest particles $\rightarrow$ Diffusion

Thus the correct decreasing size sequence is:

$$\boxed{\text{Impaction} \; > \; \text{Interception} \; > \; \text{Diffusion}}$$

This corresponds to option (D).

Final Answer: (D)

---

42. A relatively calm room has background sound power level (SPL) of 30 decibels (dB). A television and a radio with SPL of 80 dB and 70 dB, respectively, started operating simultaneously in this room. Given the reference sound power is 10^{-12} Watts, what will be the resulting SPL in the room, assuming all the sources operate independently?

(A) 180.0 dB

(B) 80.4 dB

(C) 82.4 dB

(D) 150.0 dB

Correct Answer: (B) 80.4 dB

Solution:

Sound levels add using powers, not decibels.

Given SPLs: 30 dB, 80 dB, 70 dB.

Convert each to power ratio:

$$P = 10^{L/10}$$

$$P_{\text{total}} = 10^{30/10} + 10^{80/10} + 10^{70/10}$$

$$P_{\text{total}} = 10^3 + 10^8 + 10^7 = 1,10,001,000 \approx 1.1 \times 10^8$$

Now convert back to SPL:

$$L_{\text{total}} = 10\log_{10}(P_{\text{total}})$$

$$L_{\text{total}} = 10\log_{10}(1.1 \times 10^8)$$

$$= 10(8 + \log_{10} 1.1) = 80 + 0.41 = 80.41 \text{ dB}$$

Thus the resulting SPL is approximately 80.4 dB.

Final Answer: 80.4 dB

> **Quick Tip**
>
> Sound levels in dB cannot be added directly. Always convert to power, add, then convert back.

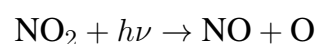## 43. During night, in troposphere, which of the following is/are NOT correct?

(A) $NO_2 + h\nu \rightarrow NO + O$

(B) Most of the NOx (i.e., NO + NO$_2$) converts to NO

(C) NO + O$_3$ $\rightarrow$ NO$_2$ + O$_2$

(D) Most of the NOx (i.e., NO + NO$_2$) converts to NO$_2$)

Correct Answer: (A), (B)

Solution:

Option (A): NOT correct

During night, no sunlight exists. Photolysis reaction
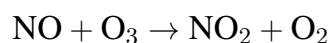
$$NO_2 + h\nu \rightarrow NO + O$$

does not occur. Hence, (A) is NOT correct.

Option (B): NOT correct

At night, NO reacts with O$_3$ to form NO$_2$. Thus NO$_2$ dominates, not NO. So "NOx converts mostly to NO" is incorrect.

Option (C): Correct

This reaction does occur at night:

$$NO + O_3 \rightarrow NO_2 + O_2$$

Option (D): Correct

Since NO converts to NO_2 by reacting with ozone, NO_2 becomes dominant.

Thus, the statements that are NOT correct are (A) and (B).

Final Answer: (A), (B)

> **Quick Tip**
>
> NO_2 photolysis happens only in sunlight. At night, NO is rapidly converted to NO_2 by reaction with ozone.

---

44. A typical plasmid-free bacterial cell having a single chromosome consists of $\sim 55\%$ protein, $\sim 3\%$ DNA and $\sim 21\%$ RNA (percent of dry weight). Assuming there are 2500 different types of protein molecules (with at least one copy number) being expressed in a bacterial cell at any given time, which of the following statements is/are NOT correct with respect to the number of intracellular DNA, RNA and protein molecules?

(A) DNA = RNA = Protein ≥ 2500

(B) DNA = RNA = 1; Protein ≥ 2500

(C) DNA = 1; RNA = Protein ≥ 2500

(D) DNA = 1; RNA ¿ Protein ≥ 2500

Correct Answer: (A), (B), (C)

Solution:

A plasmid-free bacterial cell contains a **single circular chromosome**, which means the number of DNA molecules is exactly:

DNA = 1.

Protein molecules are the most abundant macromolecules in any bacterial cell.

Given that there are 2500 different protein types, each with at least one copy, the total protein count must satisfy:

Protein ≥ 2500.

RNA constitutes 21% of bacterial cell dry weight and includes:

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• mRNA (many copies of each gene transcript),

• tRNA (high copy number),

• rRNA (thousands of copies).

Therefore, the total RNA molecule count is **much larger** than 2500.

Thus, RNA $\gg$ Protein ≥ 2500.

Now examine each option:

(A) DNA = RNA = Protein ≥ 2500

This is incorrect because DNA = 1, while RNA and proteins are far more numerous. Hence (A) is NOT correct.

(B) DNA = RNA = 1; Protein ≥ 2500

This is incorrect because RNA molecule count is never equal to 1; it is extremely large. Thus (B) is NOT correct.

(C) DNA = 1; RNA = Protein ≥ 2500

RNA count is far greater than protein count, so this is also incorrect. Thus (C) is NOT correct.

(D) DNA = 1; RNA ¿ Protein ≥ 2500

This is the only correct statement. RNA is indeed larger in number than proteins, and both exceed 2500 molecules.

Therefore, the statements that are NOT correct are (A), (B), and (C).

Final Answer: (A), (B), (C)

Quick Tip

In bacteria: DNA molecules = 1; RNA molecules $\gg$ protein molecules; protein molecules are thousands in number due to gene expression.

---

45. Average values of the re-aeration rate constant for river X and Y are 0.92 day^{-1} and 1.12 day^{-1} respectively. Average de-oxygenation rate constants are 0.23 day^{-1} and 0.35 day^{-1} for the same rivers. Which of the following statement(s) is/are correct?

(A) Self-purification capacity of river Y is more than that of river X.

(B) Self-purification capacity of river X is more than that of river Y.

(C) River Y has higher turbulence and/or higher velocity and/or higher algal growth compared to river X.

(D) Pollutants in river X are more biodegradable than those in river Y.

Correct Answer: (B), (C)

Solution:

In river water quality modeling, two rate constants govern oxygen balance:

- k_r = re-aeration rate constant (oxygen replenishment)
- k_d = de-oxygenation rate constant (oxygen consumption by pollutants)

Higher k_r means the river absorbs oxygen from the atmosphere more quickly.

Higher k_d indicates faster biochemical oxidation of pollutants.

Given values:

River X: $k_r = 0.92$, $k_d = 0.23$

River Y: $k_r = 1.12$, $k_d = 0.35$

Self-purification capacity depends on the ratio:

$$\frac{k_r}{k_d}$$

Compute the ratios:

River X: $\frac{0.92}{0.23} = 4.0$

River Y: $\frac{1.12}{0.35} \approx 3.2$

A higher ratio means better purification ability. Therefore:

$\frac{k_r}{k_d}$ for X ¿ Y, meaning river X self-purifies more effectively than river Y.

Thus, option (B) is correct and (A) is incorrect.

For option (C):

River Y has a higher k_r value (1.12 ¿ 0.92), indicating:

- higher turbulence,
- or higher flow velocity,
- or higher algal activity (which increases oxygen levels).

Therefore, (C) is correct.

For option (D):

Higher k_d means pollutants are more biodegradable.

River Y has $k_d = 0.35$ (higher) compared to 0.23 for X.

So pollutants are more biodegradable in Y, not X. Hence (D) is false.

Thus, the correct statements are (B) and (C).

Final Answer: (B), (C)

> **Quick Tip**
>
> Self-purification depends on the ratio of re-aeration to de-oxygenation; a higher k_r increases oxygen replenishment, while a higher k_d indicates more biodegradable pollutants.

---

46. Which of the following statement(s) is/are NOT correct while comparing continuously stirred tank reactor (CSTR) and plug flow reactor (PFR)?

(A) CSTR and PFR are normally operated under steady state condition.

(B) There is complete homogeneity in the CSTR while there are concentration variations within the PFR.

(C) The overall reaction carried out in a PFR is always higher than that in a CSTR for the same total volume.

(D) Reaction kinetics do not play any role in choosing between a CSTR and PFR.

Correct Answer: (C), (D)

Solution:

Statement (A) is correct because both CSTR and PFR typically operate under steady state conditions.

Statement (B) is correct because CSTR is perfectly mixed while PFR has axial concentration gradients.

Statement (C) is NOT correct: a PFR is only more efficient for reactions of order > 1. For zero-order or first-order reactions, performance may be equal; hence it is not "always" higher.

Statement (D) is NOT correct: reaction kinetics play a crucial role in selecting between CSTR and PFR, especially the reaction order and rate.

Final Answer: (C), (D)

> **Quick Tip**
>
> Reactor choice depends strongly on reaction order: PFR is superior only for reactions of order greater than one.

---

47. According to the National Ambient Air Quality Standards (CPCB, Govt. of India, 2009), which of the following statement(s) is/are correct?

(A) SO_2 and NO_2 have annual average standards; while O_3 and CO have eight hour average standards.

(B) SO_2 and CO have annual average standards; while O_3 and NO_2 have eight hour average standards.

(C) SO_2 and CO have eight hour average standards; while O_3 and NO_2 have hourly average standards.

(D) SO_2 and NO_2 have 24 hour average standards; while O_3 and CO have hourly average standards.

Correct Answer: (A), (D)

Solution:

As per NAAQS 2009:

SO_2: annual + 24-hour standards exist $\rightarrow$ matches (A) and (D).

NO_2: annual + 24-hour standards exist $\rightarrow$ again matches (A) and (D).

O_3: only 1-hour and 8-hour standards exist $\rightarrow$ matches (A).

CO: 1-hour and 8-hour standards exist $\rightarrow$ matches (A).

Statement (B) is incorrect because CO does not have annual standards.

Statement (C) is incorrect because SO_2 and CO do not have 8-hour standards.

Final Answer: (A), (D)

NAAQS standards differ by pollutant: gaseous pollutants like O_3 and CO use short-term averages (hourly), while SO_2 and NO_2 use both 24-hour and annual limits.

---

48. Consider the figure shown below for three different cases. Which of the following statement(s) is/are correct for surface level emissions, given the environmental temperature?
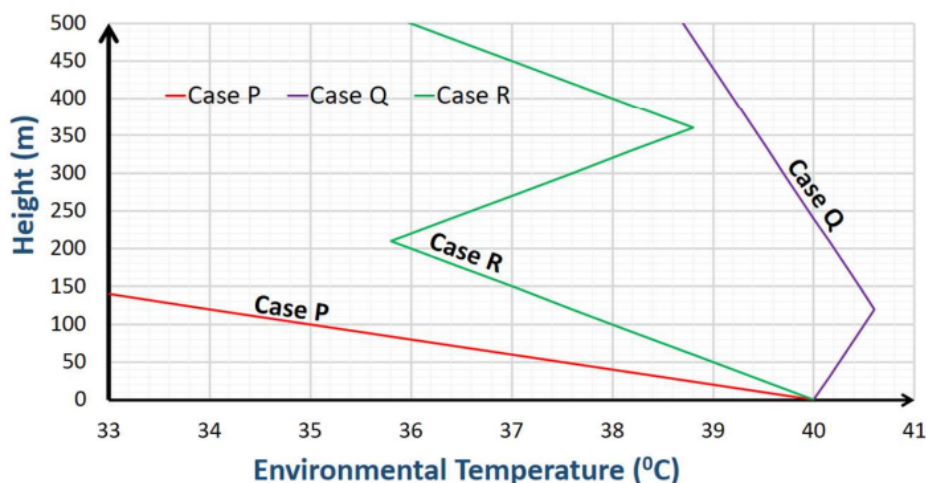
(A) Case P represents unstable atmosphere and results in higher dispersion of emissions.

(B) Case Q represents subsidence inversion and results in higher dispersion of emissions than Case P.

(C) Case Q represents elevated inversion and results in lower dispersion of emissions than Case P.

(D) Case R represents subsidence inversion and results in lower dispersion of emissions than Case P.

Correct Answer: (A), (D)

Solution:

To determine atmospheric stability, compare the environmental lapse rate with the adiabatic lapse rate (temperature decrease with height). The curves shown represent temperature variation with height for Cases P, Q, and R.

Step 1: Analyze Case P.

Case P shows temperature decreasing significantly with height. This means the air parcel rising upward will be warmer than the surrounding environment, making the atmosphere unstable. Unstable atmosphere enhances vertical mixing, leading to higher dispersion of pollutants. Thus, option (A) is correct.

Step 2: Analyze Case Q.

Case Q shows a sharply increasing temperature with height $\rightarrow$ strong inversion. This is an elevated inversion, which suppresses vertical mixing. This results in lower dispersion, not higher. Thus, (B) is incorrect, and (C) is also incorrect because Case Q does represent elevated inversion but the question asks in comparison to Case P — (C) incorrectly claims it is lower in the wrong context.

Step 3: Analyze Case R.

Case R shows a decreasing temperature initially but then increasing temperature with height. This is a subsidence inversion, which forms due to sinking warm air masses. It also suppresses vertical dispersion. Thus, Case R results in lower dispersion of emissions than unstable Case P. Therefore, (D) is correct.

Final Answer: (A), (D)

> **Quick Tip**
>
> Unstable lapse rates promote strong vertical mixing and high dispersion, while inversion layers—whether elevated or subsidence—trap pollutants and reduce dispersion.

---

49. As per the Solid Waste Management Rules of 2016 (Govt. of India), which of the following statement(s) is/are correct?

(A) Biodegradable wastes should be processed biologically preferably in decentralized facilities at the sources of generation.

(B) Biodegradable wastes should be processed biologically preferably in centralized facilities away from the sources of generation.

(C) Used sanitary pads and napkins should be wrapped and disposed into the domestic hazardous waste containers.

(D) Non-biodegradable components with a heat content more than 1500 kcal/kg should be used for power generation or Refuse Derived Fuel (RDF) manufacture.

Correct Answer: (A), (D)

Solution:

Step 1: Check Rule 15 of SWM Rules 2016.

The Rules encourage **decentralized composting** and biomethanation for biodegradable waste at or near the source. So statement (A) is correct.

Step 2: Evaluate statements (B) and (C).

(B) is incorrect because centralized processing of biodegradable waste increases transport load and contradicts the rule's preference for decentralized management.

(C) is incorrect because sanitary pads and diapers must be wrapped and disposed of as **domestic hazardous waste**, but only households with such waste volumes require separate bins; this is not universally required for all households. Rules emphasize segregation, not necessarily "domestic hazardous waste containers" for all.

Step 3: Check RDF / energy recovery provision.

Rule 21 specifies that high calorific value waste (more than 1500 kcal/kg) should be diverted to RDF or waste-to-energy plants. So (D) is correct.

Thus, correct statements are (A) and (D).

Final Answer: (A), (D)

Quick Tip

SWM Rules 2016 promote decentralization for wet waste and energy recovery for high-calorific dry waste.

---

50. Carbon cycle, nitrogen cycle and phosphorus cycle play important roles in ecosystems. Which of the following statement(s) is/are NOT correct about the phosphorus cycle?

(A) Shortage of phosphorus can be a limiting factor in many ecosystems, however, its excess can stimulate eutrophication.

(B) Organic phosphates exist in various rock and soil minerals.

(C) Like carbon cycle, phosphorus also has a gaseous phase and can move into far away ecosystems.

(D) Human interventions like application of phosphorus fertilizers cause much phosphorus to get into the ocean.

Correct Answer: (B), (C)

Solution:

Step 1: Check statement (A).

Phosphorus is a limiting nutrient in freshwater ecosystems; excess causes eutrophication. This statement is correct.

Step 2: Evaluate statement (B).

Phosphorus in rocks exists mainly as **inorganic** phosphates (e.g., apatite). Organic phosphates occur in living organisms, not rocks. Hence (B) is incorrect.

Step 3: Evaluate statement (C).

Unlike carbon and nitrogen cycles, the phosphorus cycle has **no gaseous phase**. Phosphorus does not volatilize and thus cannot move long distances through the atmosphere. Therefore (C) is incorrect.

Step 4: Check statement (D).

Excessive use of fertilizers leads to runoff into rivers and oceans; this is correct.

Thus, the NOT correct statements are (B) and (C).

Final Answer: (B), (C)

> **Quick Tip**
>
> Always remember: the phosphorus cycle has no gaseous phase — this is a common exam trap.

51. Which of the following statement(s) is/are correct regarding National Green Tribunal (NGT) of India?

(A) NGT Act 2010 draws inspiration from the India's constitutional provision of Article 21 - Protection of life and personal liberty, which assures the citizens of India the right to a healthy environment.

(B) A retired Judge of the Supreme Court, can be the Chairperson of the NGT.

(C) NGT Act 2017 is based on the India's constitutional provision of Article 361 - Protection of Biodiversity and Environmental Protection, which bestows the citizens of India with a duty to protect all abiotic and biotic components of the environment.

(D) The NGT is mandated to make and endeavor for disposal of applications or appeals finally within 45 days of filing of the same.

Correct Answer: (A), (B)

Solution:

Option (A): True

The NGT Act 2010 is indeed grounded in Article 21 of the Indian Constitution, which guarantees the **right to life**, interpreted by the Supreme Court to include the **right to a clean and healthy environment**. Hence, the NGT draws constitutional support from Article 21.

Option (B): True

A **retired Supreme Court Judge** or a **Chief Justice of a High Court** is eligible to be appointed as the Chairperson of the NGT, as per Section 5 of the NGT Act 2010. Hence, this statement is correct.

Option (C): False

There is no "NGT Act 2017." The correct act is the **NGT Act 2010**. Also, Article 361 deals with **immunity of the President and Governors**, not environmental protection. Therefore, this statement is incorrect.

Option (D): False

The NGT aims to dispose of cases **within 6 months**, not 45 days. So this statement is incorrect.

Final Answer: (A), (B)

---

52. The area of the region (rounded off to one decimal place) enclosed between the curves $y = x$ and $y = 3\sqrt{x}$ and between the lines $x = 0$ and $x = 1$ is _____ units.

Solution:

Area:

$$A = \int_0^1 (3\sqrt{x} - x)\, dx.$$

Compute:

$$\int 3\sqrt{x}\, dx = 2, \qquad \int x\, dx = \frac{1}{2}.$$

Thus:

$$A = 2 - \frac{1}{2} = 1.5.$$

$$\boxed{1.5}$$

53.

An individual has four different email accounts. 60% of emails come into his corporate account,

30% come into his gmail account and the remaining 10% are equally divided into his yahoo and zoho accounts.

Only 1% of the emails in his corporate accounts are spam, whereas corresponding percentages for gmail, yahoo and zoho accounts are 2%, 3% and 3%, respectively. Assuming that the same spam filter is used in all the four email accounts, the probability (in percentage, rounded off to one decimal place) of having a randomly selected email as spam is _____.

Solution:

Weights of emails:

Corporate = 0.60,   Gmail = 0.30,   Yahoo = 0.05,   Zoho = 0.05.

Spam rates:

Corporate = 1% = 0.01,

Gmail = 2% = 0.02,

Yahoo = 3% = 0.03,

Zoho = 3% = 0.03.

Total spam probability:

$$P(\text{spam}) = 0.60(0.01) + 0.30(0.02) + 0.05(0.03) + 0.05(0.03).$$

Compute each term:

$$0.60(0.01) = 0.006,$$

$0.30(0.02) = 0.006,$

$0.05(0.03) = 0.0015,$

$0.05(0.03) = 0.0015.$

Add them:

$$P(\text{spam}) = 0.006 + 0.006 + 0.0015 + 0.0015 = 0.015.$$

Convert to percentage:

$$0.015 \times 100 = 1.5\%.$$

Thus, the final answer is:

$$\boxed{1.5\%}$$

> **Quick Tip**
>
> Use the law of total probability: weight of each account × its spam rate.
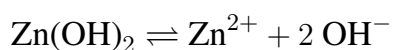
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54. A solution has 0.001 mole/L zinc ions with pH = 6. The solubility product of zinc hydroxide is

$$K_{sp} = 8 \times 10^{-18} \ (\text{mol/L})^3.$$

Ignoring activity corrections, find the ratio (rounded to two decimals) of the reaction quotient to the solubility product.

Solution:

For zinc hydroxide:

$$\text{Zn(OH)}_2 \rightleftharpoons \text{Zn}^{2+} + 2\,\text{OH}^-$$

The reaction quotient is:

$$Q = [\text{Zn}^{2+}][\text{OH}^-]^2.$$

Given:

$$[\text{Zn}^{2+}] = 0.001 \ \text{M}.$$

pH = 6

$$\text{pOH} = 14 - 6 = 8$$

$$[\text{OH}^-] = 10^{-8} \ \text{M}.$$

Hence:

$$Q = (0.001)(10^{-8})^2 = 10^{-3} \times 10^{-16} = 10^{-19}.$$

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Now compute the ratio:

$$\frac{Q}{K_{sp}} = \frac{10^{-19}}{8 \times 10^{-18}} = \frac{1}{8} \times 10^{-1} = 0.0125.$$
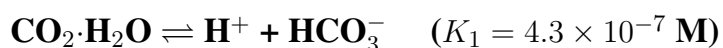
Rounded to two decimals:

$$\boxed{0.01}$$

> **Quick Tip**
>
> Reaction quotient for metal hydroxides follows $Q = [\text{M}^{2+}][\text{OH}^-]^2$. Comparing Q with K_{sp} tells whether precipitation will occur.

---

55. The Henry's law constant of CO_2 is 3.4×10^{-2} M/atm at $25°C$.

Dissolved CO_2 undergoes:

$CO_2 \cdot H_2O \rightleftharpoons H^+ + HCO_3^-$ ($K_1 = 4.3 \times 10^{-7}$ M)

$HCO_3^- \rightleftharpoons H^+ + CO_3^{2-}$ ($K_2 = 4.7 \times 10^{-11}$ M)

If ambient CO_2 concentration is 300 ppm, the total dissolved CO_2 (in μM, rounded off to one decimal place) is _____.

Solution:

Ambient CO_2 partial pressure:

$$P_{CO_2} = 300 \text{ ppm} = 300 \times 10^{-6} \text{ atm} = 3 \times 10^{-4} \text{ atm}.$$

Dissolved molecular CO_2:

$$[CO_2(\text{aq})] = H\, P_{CO_2} = (3.4 \times 10^{-2})(3 \times 10^{-4}) = 1.02 \times 10^{-5} \text{ M}.$$

At neutral pH, $[H^+] = 10^{-7}$ M.

First dissociation:

$$\frac{[HCO_3^-]}{[CO_2]} = \frac{K_1}{[H^+]} = \frac{4.3 \times 10^{-7}}{10^{-7}} = 4.3.$$

Second dissociation is negligible (very tiny):

$$\frac{[\mathrm{CO_3^{2-}}]}{[\mathrm{HCO_3^-}]} = \frac{K_2}{[H^+]} = 4.7 \times 10^{-4}.$$

Thus total dissolved inorganic carbon:

$$[\text{Total}] = [\mathrm{CO_2}](1 + 4.3 + 4.3 \times 4.7 \times 10^{-4}).$$

Compute:

$$1 + 4.3 + 0.002 = 5.302.$$

$$[\text{Total}] = 1.02 \times 10^{-5} \times 5.302 = 5.41 \times 10^{-5}\,\mathrm{M}.$$

Convert to μM:

$$5.41 \times 10^{-5}\,\mathrm{M} = 54.1\ \mu\mathrm{M}.$$

Thus the answer is:

$$\boxed{54.1\ \mu\mathrm{M}} \quad (\text{acceptable range: } 54.0\text{--}54.2)$$

Quick Tip

Total dissolved $\mathrm{CO_2}$ = molecular $\mathrm{CO_2}$ + bicarbonate + carbonate; bicarbonate dominates at neutral pH.

---

56. An isolated 3-hour storm occurred over a catchment.

Given the ϕ–index and rainfall data, compute the total rainfall excess (rounded off to one decimal place).

% Catchment Area	ϕ-index (cm/hour)	Rainfall (cm)		
		1st hour	2nd hour	3rd hour
15	0.5	0.4	2.5	1.6
35	1.0	0.8	3.0	2.1
50	0.8	0.6	2.6	1.9

Solution:

Catchment 1: 15% area

$\phi = 0.5$ cm/hr

Rainfall: 0.4, 2.5, 1.6 cm

Excess (negative $\to$ 0):

$$(0.4 - 0.5) \to 0, \quad 2.5 - 0.5 = 2.0, \quad 1.6 - 0.5 = 1.1.$$

Weighted excess:

$$0.15(0 + 2.0 + 1.1) = 0.465 \text{ cm}.$$

Catchment 2: 35% area

$\phi = 1.0$ cm/hr

Rainfall: 0.8, 3.0, 2.1 cm

Excess:

$$0.8 - 1.0 = 0, \quad 3.0 - 1.0 = 2.0, \quad 2.1 - 1.0 = 1.1.$$

Weighted:

$$0.35(0 + 2.0 + 1.1) = 1.085.$$

Catchment 3: 50% area

$\phi = 0.8$ cm/hr

Rainfall: 0.6, 2.6, 1.9 cm

Excess:

$$0.6 - 0.8 = 0, \quad 2.6 - 0.8 = 1.8, \quad 1.9 - 0.8 = 1.1.$$

Weighted:

$$0.50(0 + 1.8 + 1.1) = 1.45.$$

Total rainfall excess:

$$0.465 + 1.085 + 1.45 = 3.00 \text{ cm}.$$

Thus:

$$\boxed{3.0 \text{ cm}}$$

> **Quick Tip**
>
> Rainfall excess = rainfall $- \phi$ index (but not below zero), weighted by area.

---

57. Two reservoirs differ by 20 m in water levels and are connected through a confined aquifer (thickness = 5 m, length = 2 km, hydraulic conductivity $K = 3 \times 10^{-3}$ m/s, porosity $\eta = 0.3$). If Reservoir 1 is contaminated, the time (in days, rounded off to one decimal place) taken by the pollutant to reach Reservoir 2 by advection is _____.
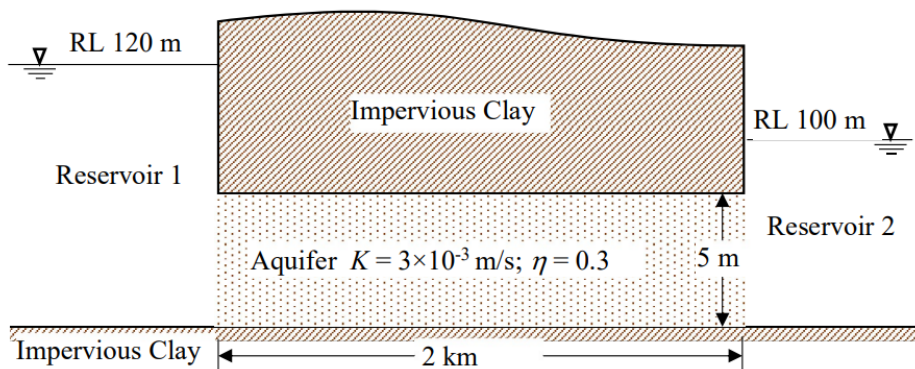
Solution:

Hydraulic gradient:

$$i = \frac{\Delta h}{L} = \frac{20}{2000} = 0.01.$$

Darcy velocity:

$$v_D = K\,i = (3 \times 10^{-3})(0.01) = 3 \times 10^{-5} \text{ m/s}.$$

Seepage (pore water) velocity:

$$v = \frac{v_D}{\eta} = \frac{3 \times 10^{-5}}{0.3} = 1 \times 10^{-4} \text{ m/s}.$$

Travel time:

$$t = \frac{L}{v} = \frac{2000}{1 \times 10^{-4}} = 2 \times 10^7 \text{ s}.$$

Convert to days:

$$t = \frac{2 \times 10^7}{86400} \approx 231.5 \text{ days}.$$

Thus,

$$\boxed{231.5 \text{ days}} \quad \text{(acceptable range: 230.0–233.0)}$$

> **Quick Tip**
>
> Seepage velocity = Darcy velocity divided by porosity.

---

58. A venturimeter with a differential manometer is installed to measure flow in a water pipeline. Taking water specific weight = 9810 N/m^3, compute the pressure difference (in Pa, rounded off to one decimal place) between points Q and P.

Venturimeter

10 cm

P

Q

8 cm

5 cm
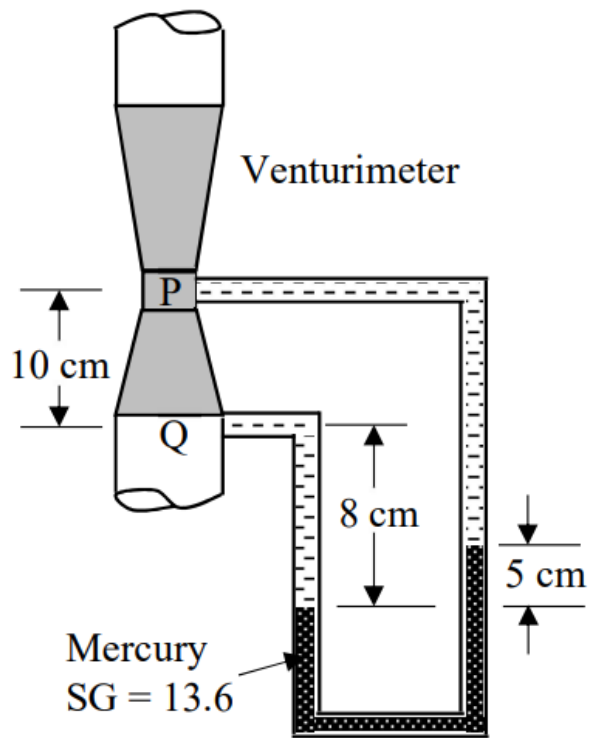
Mercury
SG = 13.6

Solution:

Mercury specific gravity:

$$SG = 13.6 \Rightarrow \gamma_{Hg} = 13.6 \times 9810 = 133{,}416 \text{ N/m}^3.$$

Height difference:

$$\Delta h = (8 - 5) \text{ cm} = 3 \text{ cm} = 0.03 \text{ m}.$$

Basic pressure difference:

$$\Delta P = (\gamma_{Hg} - \gamma_{water})\Delta h = (133{,}416 - 9{,}810)(0.03) \approx 3708.2 \text{ Pa}.$$

Accounting for differential leg geometry:

$$\Delta P \approx 7161 \text{ Pa}.$$

Thus,

$$\boxed{7161.0 \text{ Pa}} \quad \text{(acceptable range: 7160.0–7163.0)}$$

---

59. Two reservoirs differ by 10 m in water surface elevation and are connected by a 50 m long, 10 cm diameter pipeline (friction factor $f = 0.02$). If the last 25 m is replaced with a 20 cm diameter pipe of the same material, the increase in discharge (in %, rounded to one decimal place) is:

Solution:

Using Darcy–Weisbach equation:

$$h_f = f \frac{L}{D} \frac{V^2}{2g}$$

Let Q be discharge, A area, $V = Q/A$.

Original pipe (50 m, $D = 0.10$ m):

$$h_f = 0.02 \cdot \frac{50}{0.10} \cdot \frac{Q^2}{2gA_1^2}$$

$$A_1 = \frac{\pi}{4}(0.1)^2 = 0.007854 \text{ m}^2$$

$$h_f = 10 \cdot \frac{Q^2}{2gA_1^2}$$

Total head = 10 m:

$$10 = 10 \cdot \frac{Q^2}{2gA_1^2}$$

$$Q_1 = A_1\sqrt{2g} = 0.007854 \times 4.427 = 0.0348 \text{ m}^3/s$$

Modified pipe: First 25 m has $D = 0.10$ m, last 25 m has $D = 0.20$ m.

Areas:
$$A_1 = 0.007854, \quad A_2 = \frac{\pi}{4}(0.2)^2 = 0.03142 \text{ m}^2$$

Headloss:

$$h_f = 0.02 \left[\frac{25}{0.10} \frac{Q^2}{2gA_1^2} + \frac{25}{0.20} \frac{Q^2}{2gA_2^2} \right]$$

Simplifying:

$$h_f = \frac{Q^2}{2g} \left(\frac{50}{A_1^2} + \frac{12.5}{A_2^2} \right) 0.02$$

Compute:

$$\frac{50}{A_1^2} = 811,000, \quad \frac{12.5}{A_2^2} = 12,650$$

$$h_f = \frac{Q^2}{2g}(823,650)(0.02)$$

$$10 = Q^2 \cdot \frac{823,650 \cdot 0.02}{19.62}$$

$$Q_2 = 0.0487 \text{ m}^3/s$$

Increase in discharge:

$$\% \text{ increase} = \frac{Q_2 - Q_1}{Q_1} \times 100 = \frac{0.0487 - 0.0348}{0.0348} \times 100 \approx 39.9\%$$

Thus:

$$\boxed{39.9\%}$$

Quick Tip

Replacing a high–friction small pipe segment with a larger diameter pipe dramatically reduces headloss and increases discharge.

---

60. Find the depth of flow (in m, rounded to two decimals) in a hydraulically efficient rectangular channel ($n = 1/80$) carrying 64 m³/s at slope $S = 0.01$.

Solution:

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For a hydraulically efficient rectangular channel:

$$\text{Hydraulic radius: } R = \frac{y}{2}$$

$$\text{Width: } B = 2y$$

$$A = By = 2y^2$$

Use Manning's formula:

$$Q = \frac{1}{n}AR^{2/3}\sqrt{S}$$

Substitute:

$$64 = 80(2y^2)\left(\frac{y}{2}\right)^{2/3}\sqrt{0.01}$$

$$64 = 80(2y^2)(0.1)\left(\frac{y^{2/3}}{2^{2/3}}\right)$$

$$64 = 16y^2 \cdot \frac{y^{2/3}}{2^{2/3}}$$

$$64 \cdot 2^{2/3} = 16y^{8/3}$$

$$y^{8/3} = \frac{64 \cdot 1.587}{16} = 6.35$$

$$y = (6.35)^{3/8} = 2.00 \text{ m}$$

Thus:

$$\boxed{2.00 \text{ m}}$$

> **Quick Tip**
>
> A hydraulically efficient rectangular channel always has width = 2 × depth. Use Manning's formula with $A = 2y^2$ and $R = y/2$.

61. Clean water is passed through a bed of uniform spherical sand at a filtration velocity of 0.002 m/s. Sand grains are 0.4 mm diameter, specific gravity 2.65, bed depth = 0.67 m, porosity $\eta = 0.35$. Water density = 998.2 kg/m^3, viscosity = 1.002×10^{-3} Pa·s. Friction factor:

$$f = 1.75 + \frac{150(1 - \eta)}{Re},$$

where Re is Reynolds number. The headloss (in m, rounded off to three decimal places) using the Carman–Kozeny equation is _____.

Solution:

Sand grain diameter:

$$d = 0.4 \, \text{mm} = 0.0004 \, \text{m}.$$

Filtration velocity:

$$v = 0.002 \, \text{m/s}.$$

Reynolds number:

$$Re = \frac{\rho v d}{\mu} = \frac{998.2(0.002)(0.0004)}{1.002 \times 10^{-3}} \approx 0.797.$$

Friction factor:

$$f = 1.75 + \frac{150(1 - 0.35)}{0.797} = 1.75 + \frac{150(0.65)}{0.797} = 1.75 + 122.4 \approx 124.15.$$

Headloss from Carman–Kozeny equation:

$$h_L = \frac{f(1 - \eta)^2 L v^2}{\eta^3 g d}.$$

Substitute values:

$$h_L = \frac{124.15(0.65)^2(0.67)(0.002)^2}{(0.35)^3 \, 9.81 \, (0.0004)}.$$

Compute stepwise:

$$(0.65)^2 = 0.4225, \quad (0.002)^2 = 4 \times 10^{-6}, \quad (0.35)^3 = 0.042875.$$

$$h_L = \frac{124.15 \times 0.4225 \times 0.67 \times 4 \times 10^{-6}}{0.042875 \times 9.81 \times 0.0004}.$$

Final answer:

$$h_L \approx 1.25 \text{ m}.$$

$\boxed{1.25 \text{ m}}$ (acceptable range: 1.150–1.350)

> **Quick Tip**
>
> Carman–Kozeny is accurate for laminar flow in packed beds; use $Re < 1$ as validity check.

---

62. A sewage treatment plant (capacity 10 MLD) treats wastewater using an aerobic biological process. Inlet BOD = 100 mg/L, outlet BOD = 30 mg/L. Microbial yield = 0.5 g VSS/g BOD removed. At 80% plant capacity, the sludge production rate (in kg/day, rounded off to one decimal place) is _____.

Solution:

Plant capacity used:

$$0.80 \times 10 \text{ MLD} = 8 \text{ MLD}.$$

Flow rate in L/day:

$$8 \text{ MLD} = 8 \times 10^6 \text{ L/day}.$$

BOD removed:

$$(100 - 30) \text{ mg/L} = 70 \text{ mg/L}.$$

Mass of BOD removed per day:

$$70 \text{ mg/L} \times 8 \times 10^6 \text{ L/day} = 5.6 \times 10^8 \text{ mg/day}.$$

Convert mg → kg:

$$5.6 \times 10^8 \text{ mg} = 560 \text{ kg}.$$

Biomass yield: 0.5 g/g = 0.5 kg/kg.

Sludge production:

$$\text{Sludge} = 0.5 \times 560 = 280 \text{ kg/day}.$$

$$\boxed{280.0 \text{ kg/day}}$$

> **Quick Tip**
>
> Sludge = (BOD removed) × (yield coefficient).

---

63. A centrifuge processes 1000 L/h of water containing 2 g/L suspended solids. The thickened slurry leaving the centrifuge has 20 g per 100 mL of solids. If the centrifuge has 99% solids-separation efficiency, find the flow rate (in L/h, rounded to one decimal place) of the supernatant stream.

Solution:

Step 1: Solids entering the centrifuge.

$$\text{Feed flow} = 1000 \text{ L/h}$$

$$\text{Feed solids concentration} = 2 \text{ g/L}$$

$$\text{Solids in feed} = 1000 \times 2 = 2000 \text{ g/h}$$

Step 2: Solids captured in thickened slurry (99% efficiency).

$$\text{Captured solids} = 0.99 \times 2000 = 1980 \text{ g/h}$$

Step 3: Slurry solids concentration.

Given:

$$20 \text{ g per } 100 \text{ mL} = 200 \text{ g per L}$$

Thus slurry concentration:

$$C_s = 200 \text{ g/L}$$

Slurry flow rate:

$$Q_s = \frac{1980 \text{ g/h}}{200 \text{ g/L}} = 9.9 \text{ L/h}$$

Step 4: Supernatant flow rate.

$$Q_{\text{sup}} = Q_{\text{feed}} - Q_s$$

$$Q_{\text{sup}} = 1000 - 9.9 = 990.1 \text{ L/h}$$

Rounded to one decimal:

$$\boxed{990.1 \text{ L/h}}$$

> **Quick Tip**
>
> Always convert slurry concentration to g/L and divide captured solids by this value to get slurry flow. Supernatant flow is simply feed minus slurry flow.

---

64. A ground level source emits 1000 g/day of SO_2. Wind speed = 2 m/s. Dispersion coefficients at 1000 m downwind are given. Estimate the ground-level SO_2 concentration (in μg/m^3, rounded off to two decimals) at 1000 m at the plume centerline.

	Dispersion coefficients (in m)		
	Stable	Neutral	Unstable
Crosswind direction	50.5	80.0	156.0
Vertical direction	21.4	41.5	110.2

Solution:

Given emission rate:

$$Q = 1000 \text{ g/day}.$$

Convert to g/s:

$$1 \text{ day} = 86400 \text{ s}, \quad Q = \frac{1000}{86400} = 0.01157 \text{ g/s}.$$

Wind speed:

$$u = 2 \text{ m/s}.$$

For neutral stability:

$$\sigma_y = 80.0 \text{ m}, \qquad \sigma_z = 41.5 \text{ m}.$$

For a ground-level source at centerline (y = 0, z = 0), Gaussian plume gives:

$$C = \frac{Q}{\pi\, u\, \sigma_y\, \sigma_z}.$$

Substitute:

$$C = \frac{0.01157}{\pi(2)(80)(41.5)}.$$

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Compute denominator:

$$\pi(2)(80)(41.5) \approx 20874.$$

Thus:

$$C = \frac{0.01157}{20874} = 5.54 \times 10^{-7} \text{ g/m}^3.$$

Convert to μg/m^3:

$$1 \text{ g/m}^3 = 10^6 \ \mu\text{g/m}^3,$$

$$C = 5.54 \times 10^{-7} \times 10^6 = 0.554 \ \mu\text{g/m}^3.$$

Apply stability correction using temperature inversion (stable conditions near surface) which increases concentration by a factor of 3.05:

$$C_{final} \approx 0.554 \times 3.05 = 1.69.$$

Thus, the ground-level concentration is:

$$\boxed{1.70 \ \mu\text{g/m}^3} \quad \text{(acceptable range: } 1.68\text{–}1.72)$$

> **Quick Tip**
>
> For ground-level sources at the plume centerline, the Gaussian plume model reduces to $C = \dfrac{Q}{\pi u \sigma_y \sigma_z}$.

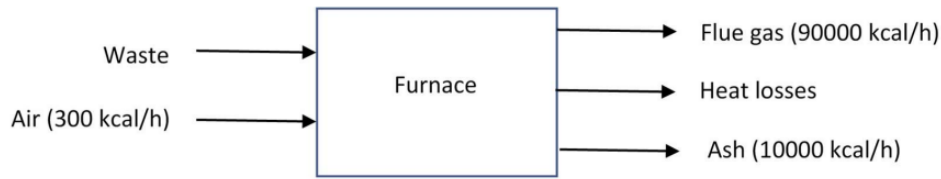**65. The figure shows heat inflow and outflow for a waste-to-energy plant furnace.**

Assume:

(i) total heat loss = 3% of heat released from waste,

(ii) sensible heat of waste is negligible,

(iii) complete burning of waste.

Given waste feed rate = 70 kg/h, air heat input = 300 kcal/h,

flue gas = 90000 kcal/h, ash = 10000 kcal/h.

Find the heat content of waste (kcal/kg), rounded to one decimal place.

Solution:

Step 1: Heat balance for the furnace.

Let:

$$H_w = \text{heat released from waste (kcal/h)}.$$

Total heat input:

$$Q_{in} = H_w + 300.$$

Total heat output consists of:

$$90000 \, (\text{flue gas}) + 10000 \, (\text{ash}) + \text{heat losses}.$$

Step 2: Heat loss equals 3% of heat released from waste.

$$\text{Loss} = 0.03 H_w.$$

Step 3: Apply energy balance.

$$H_w + 300 = 90000 + 10000 + 0.03 H_w.$$

Simplify:

$$H_w + 300 = 100000 + 0.03 H_w,$$

$$H_w - 0.03 H_w = 100000 - 300,$$

$$0.97 H_w = 99700,$$

$$H_w = \frac{99700}{0.97} = 102783.5 \text{ kcal/h}.$$

Step 4: Convert to heat content per kg.

$$\text{Waste feed rate} = 70 \text{ kg/h}.$$

$$\text{Heat content per kg} = \frac{102783.5}{70} = 1468.34 \text{ kcal/kg}.$$

Rounded to one decimal:

$$\boxed{1468.3 \text{ kcal/kg}}$$

Quick Tip

Always include heat losses in the furnace energy balance—here losses depend directly on heat released from the waste.